# SPE Distinguished Lecturer Program

The SPE Distinguished Lecturer Program is funded principally through a grant from the **SPE Foundation**.

The society gratefully acknowledges the companies that support this program by allowing their professionals to participate as lecturers.

Special thanks to the American Institute of Mining, Metallurgical, and Petroleum Engineers (AIME) for its contribution to the program.

# Perforating with Lasers: Are You Ready for the Power of Light?

**Brian C. Gahan, PE**
**Laser Rock Technologies LLC**

Society of Petroleum Engineers
Distinguished Lecturer Program
www.spe.org/dl

# Presentation Outline

- Laser Applications Background
- Downhole Laser Selection
- Perforation Tests
- HPFL Field Applications Examples
- Summary

# Specific Energy Defined

$$SE = \frac{\text{Energy Input}}{\text{Volume Removed}} = \frac{P}{dV/dt}$$

$$= \frac{kW}{cm^3/sec} = \frac{kJ}{cm^3}$$

**Lower SE Value = Higher Efficiency**

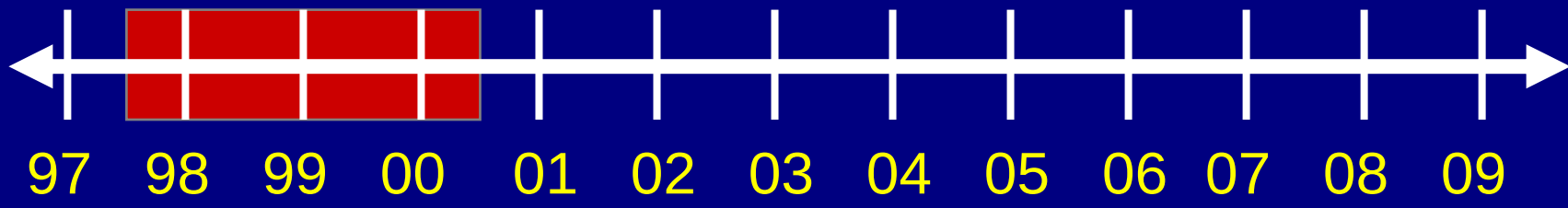
Reference: SPE 77627

# High Power Military Lasers

Q: Can Lasers Penetrate All Rock?

A: Yes, But Inefficient and Expensive

| Type | Power (kW) | Λ (μm) | Location |
|---|---|---|---|
| **COIL** | 6.8 | 1.34 | USAF |
| **$CO_2$** | 50,150 | 10.6 | USAF |
| **MIRACL** | 1600 | 3.4 | US Army |



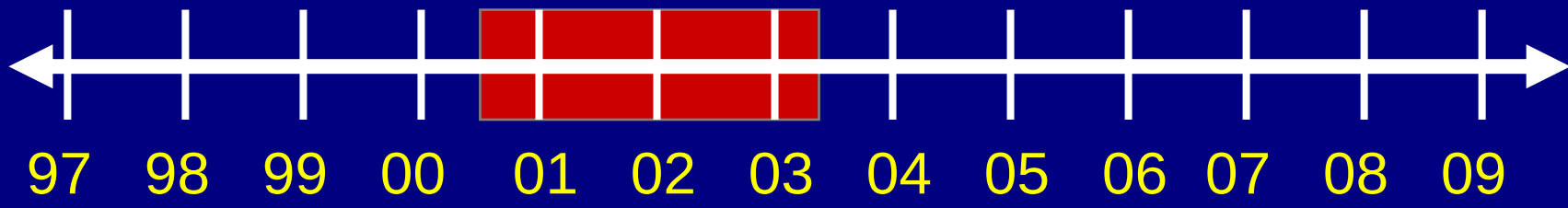

Reference: SPE 56625

# High Power Industrial Lasers

Q: How Much Energy Does it Take?

A: Much Less Than Literature Predicted

| Type | Power (kW) | Λ (μm) | Location |
|---|---|---|---|
| **Nd:YAG** | 1.6 | 1.06 | ANL |
| **$CO_2$** | 6 | 10.6 | ANL |
| **Diode** | 4 | 0.8 | NA Tech |



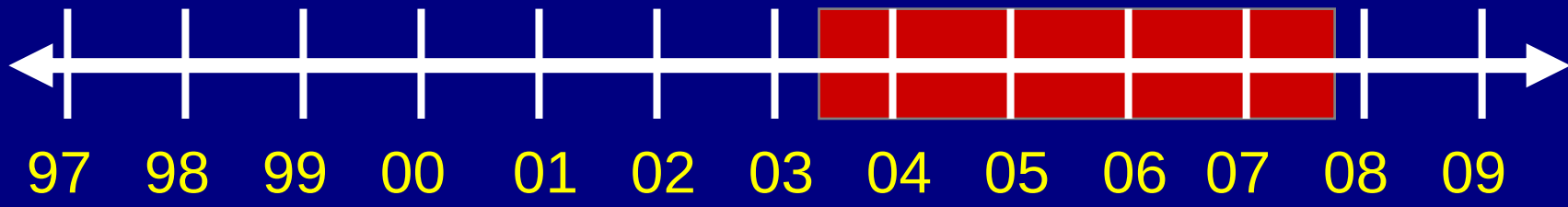

Reference: SPE 71466, 84353

# High Power Fiber Lasers

Q: Can HPFL Achieve Downhole Goals?

A: Results to Date Suggest Yes….

| Type | Power (kW) | Λ (μm) | Location |
|---|---|---|---|
| **HPFL** | ≥ 5.34 | 1.07 | GTI, LRT |




Reference: SPE 90661, 97093

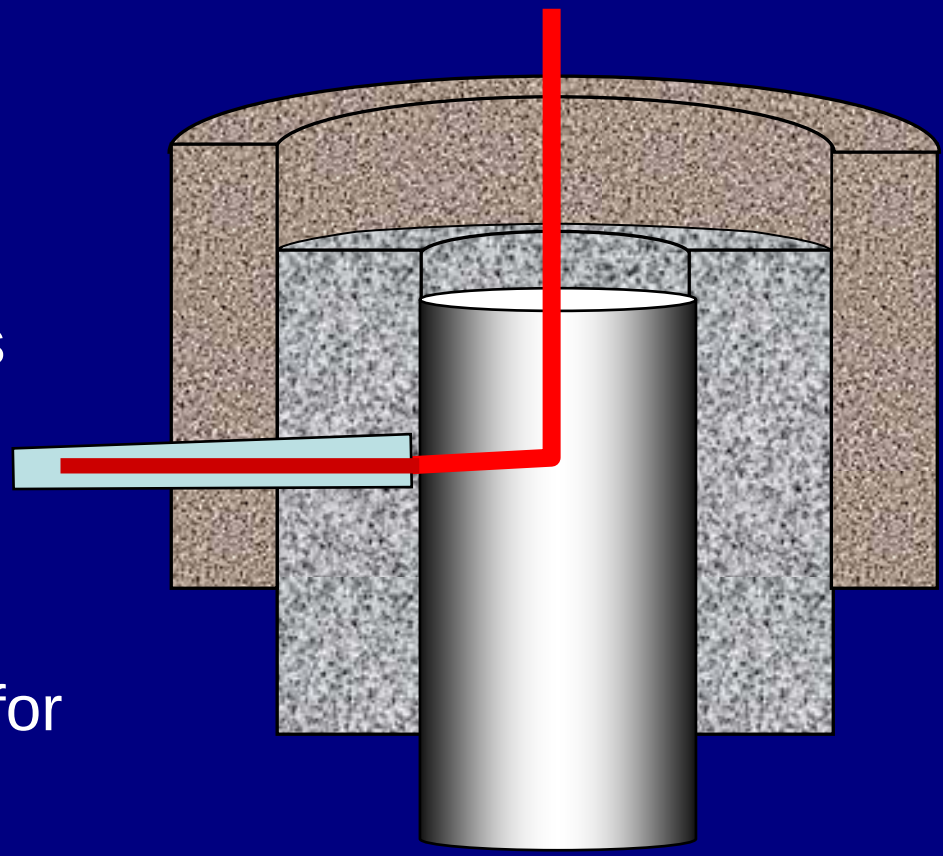
# Laser Removal Mechanisms

- Several Methods Observed
- Function of Thermal Properties
  - Carbonates – Dissociation

    $CaCO_3 \rightarrow CaO + CO_2$
  - Sandstones – Spallation
  - Shales – Spallation
  - Steel - Melt

# Downhole Laser Applications

- Drilling
- Perforating
- Seismic Shot Holes
- Casing Cutting/ Abandonment
- Offshore Platform Abandonment
- Casing “Windows” for Multi-Laterals
- Downhole Slotted Liners/Screens



# Benefits of Laser Perforation

- Non-Explosive Technology
- Real-Time Control:  Input vs. Output
- Open Geometry Solutions
- Potential for “Extended Perforation” and Other Completion Methods
- Improves Flow Conditions
  - No Mass Transfer Into Tunnel
  - Permeability/Porosity Improvements

# Presentation Outline

- Laser Applications Background
- Downhole Laser Selection
- Perforation Tests
- HPFL Field Applications Examples
- Summary

# Downhole Laser Selection

- Technical
  - Provide Required Output Power
  - Deliver Beam to Downhole Target
  - Operate at Downhole Conditions
  - Cut / Drill Multiple Materials
  - Mobile, Rugged On-site Deployment

# Downhole Laser Selection

- Economic
  - Existing, Commercially Available
  - Minimal Maintenance and Repair
  - High Energy Conversion Efficiencies
  - Minimal Energy Losses
    - Attenuation
    - Absorbtion

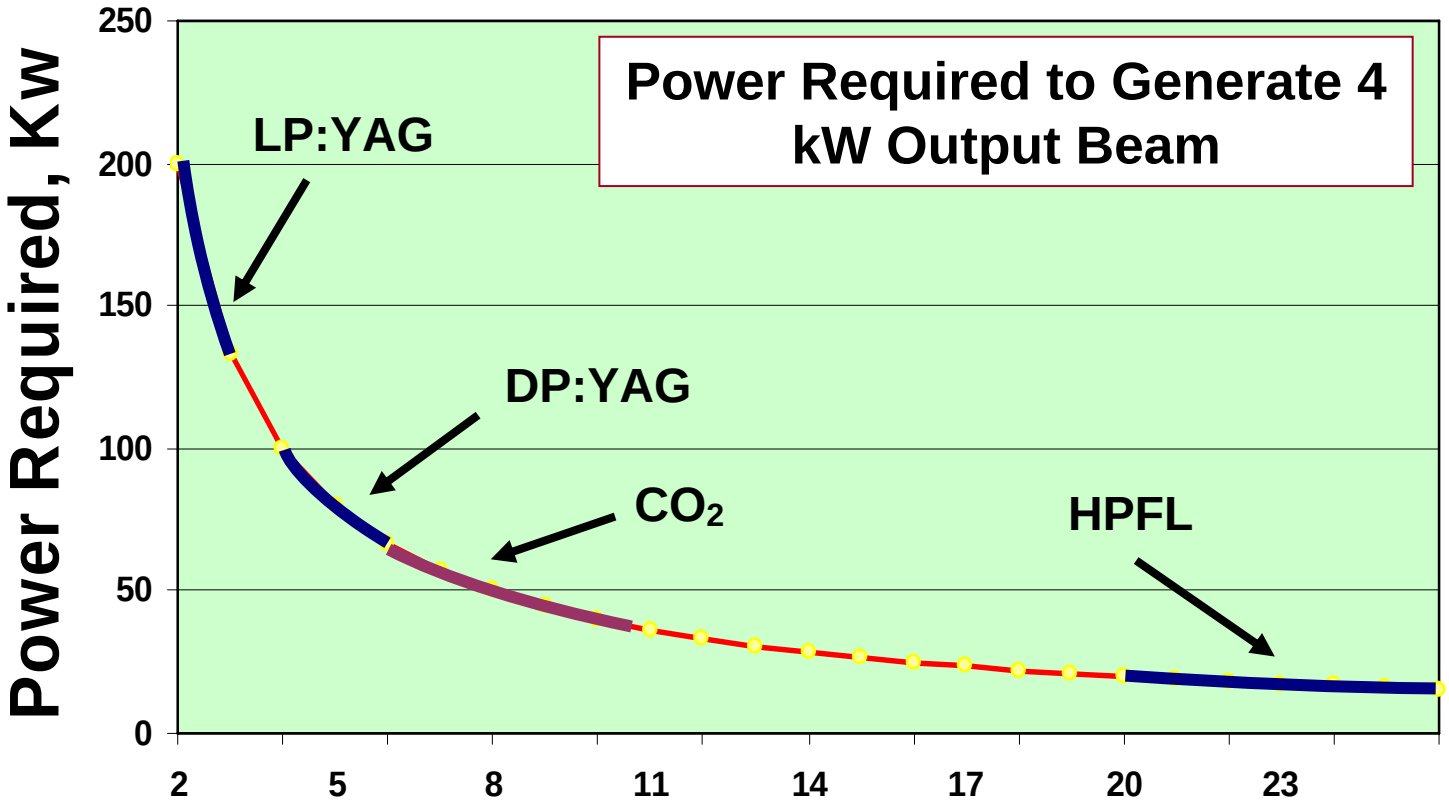
# All Lasers Are Not Equal

## Laser Parameters - 4kW Beam

| | $CO_2$ | LP:YAG | DP:YAG | HPFL |
|---|---|---|---|---|
| E/O Efficiency, % | **5-10** | **2-3** | **4-6** | **20-30** |
| Electric Power, kW (no chiller) | **40-80** | **130-200** | **67-100** | **13-20** |
| Footprint, $m^2$ (no chiller) | **6** | **5** | **3** | **0.5** |
| Water, $m^3$/hr | **6-8** | **20-25** | **~ 15** | **<2** |
| Maintenance, Khrs | **1-2** | **0.5** | **2-3** | **10-15** |
| Pump Replace, Khrs | **n/a** | **0.5-1** | **2.5** | **>100** |

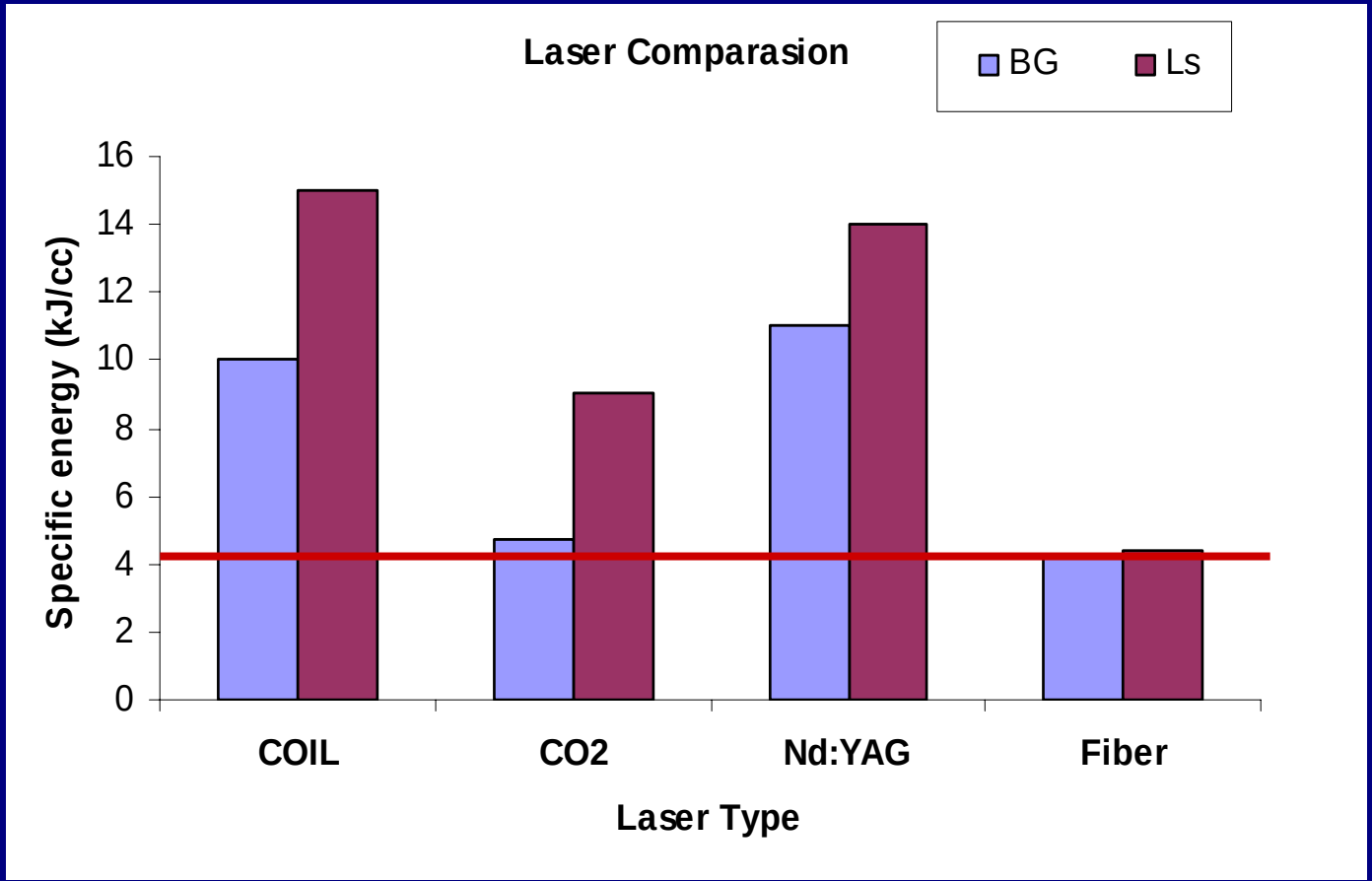
# All Lasers Are Not Equal

## Power Required for 4kW Beam



# All Lasers Are Not Equal

## Comparison of Lowest SE




Source: ICALEO

# High Power Fiber Laser (HPFL)

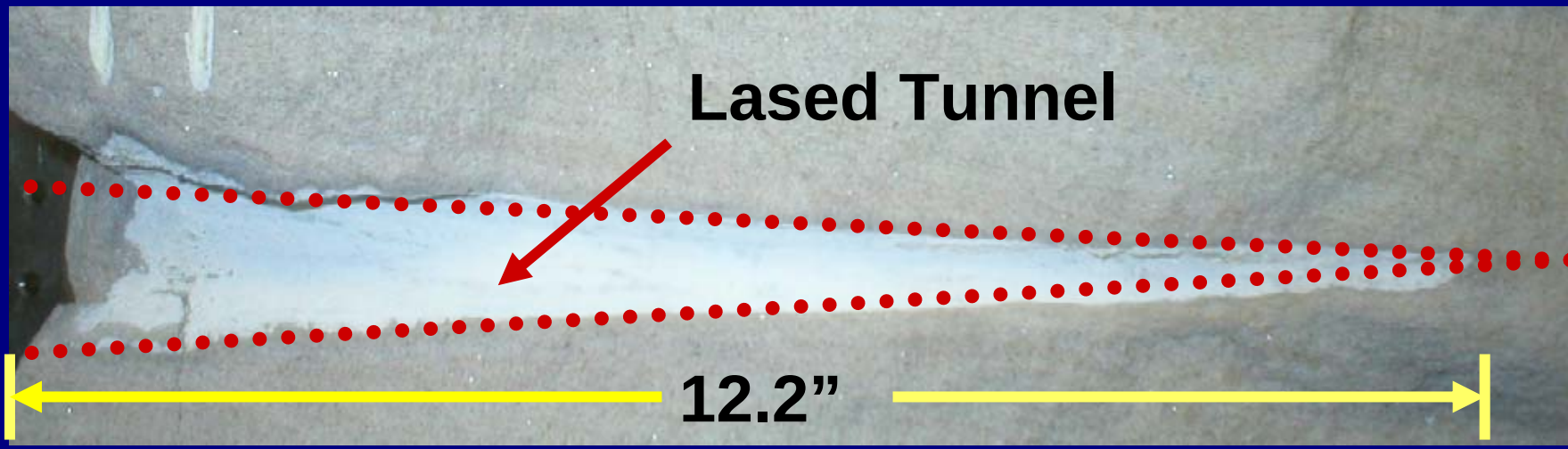
- Power: Up to 36 kW + /unit
- Wavelength: Yb: 1070 nm
- E/O Efficiency: 20-30%
- Size (10 kW):
  - 60 x 80 x 160 cm
    (2.0 x 2.5 x 5.25 ft)
  - Footprint: 0.5 $m^2$ (5.38 $ft^2$)
  - Weight:  400 kg (882 lb)

**Source: ALAC**

# Presentation Outline

- Laser Applications Background
- Downhole Laser Selection
- Perforation Tests
- HPFL Field Applications Examples
- Summary

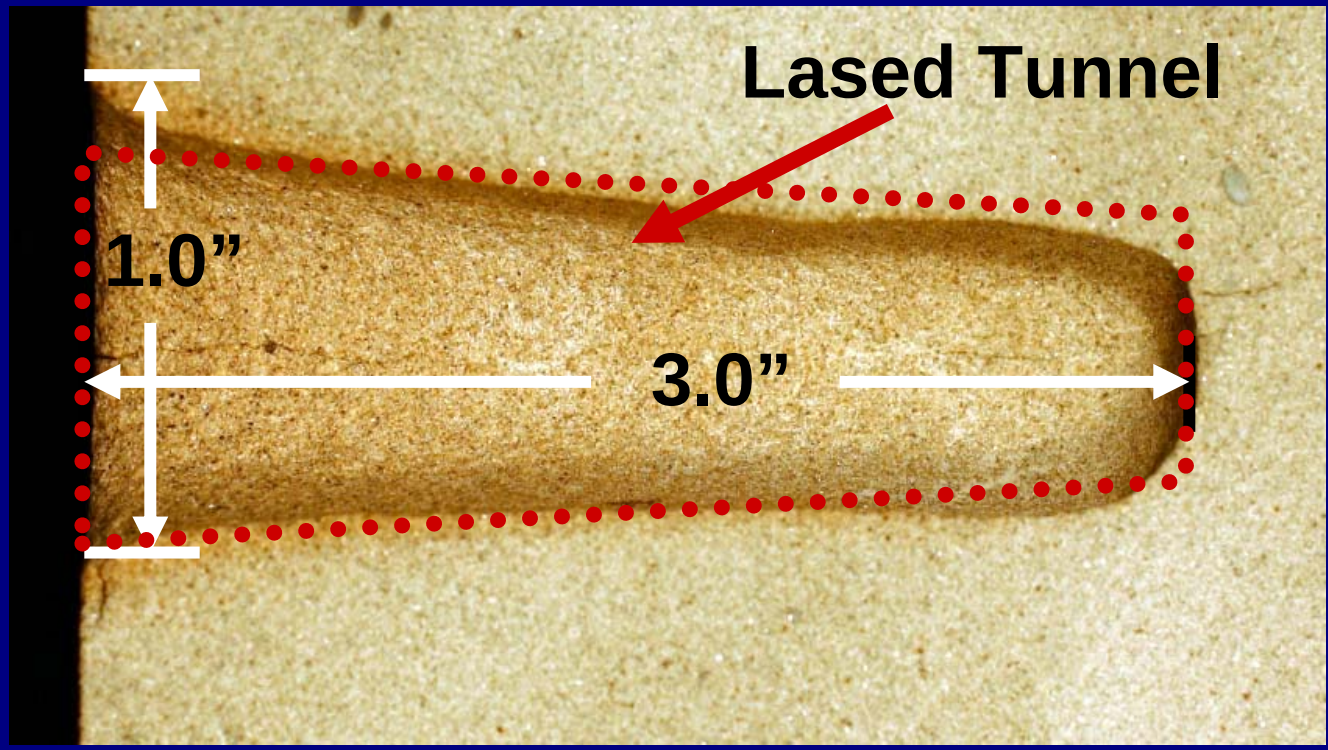
# HPFL Perforation: Limestone




Source: ALAC

**HPFL Perforation in Quarry Limestone**
**Length: 12.2 inches  Power: 5.34 kW  Beam: CW**

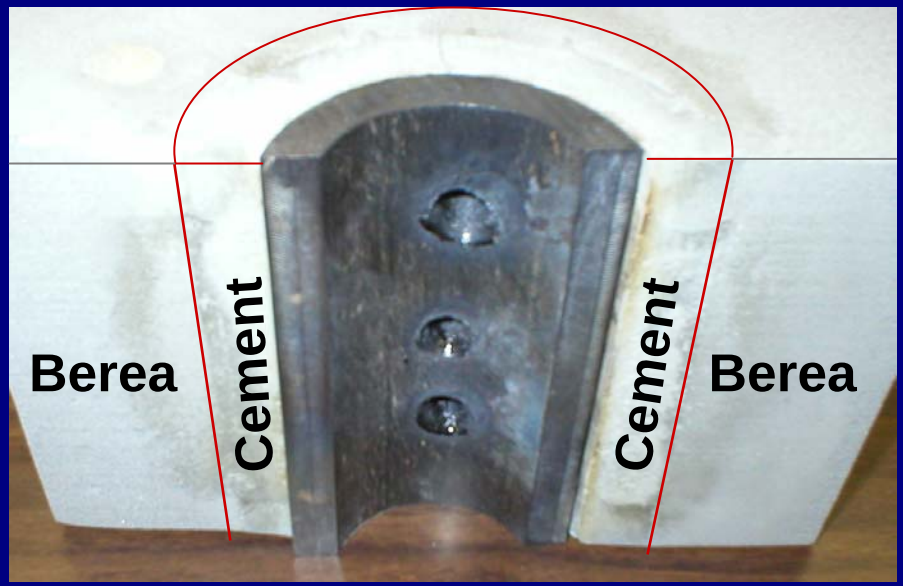
# HPFL Perforation: Sandstone




**HPFL Perforation in Berea Sandstone**
**Length: 3.0 inches  Power: 3 kW  Beam: CW**

**Source: ICALEO**

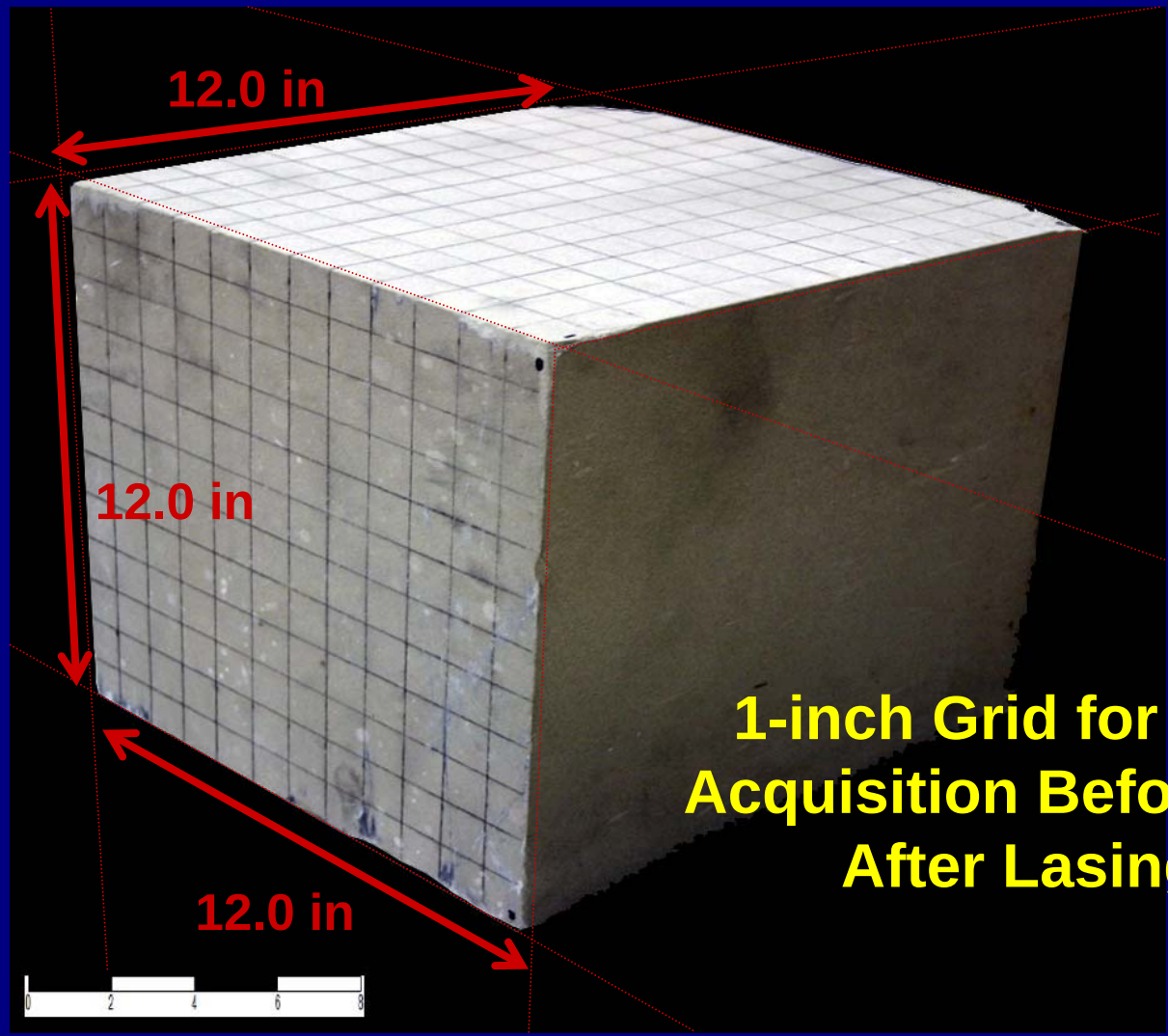
# HPFL Perforation: Composite




Source: ALAC

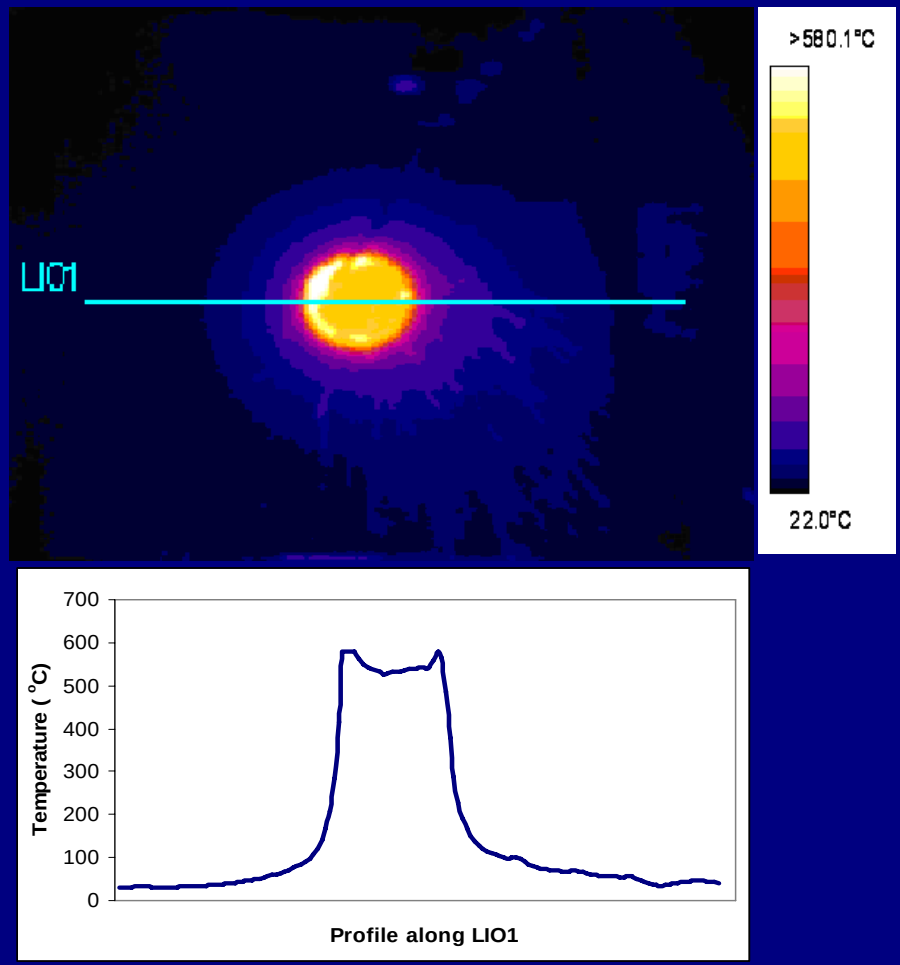
**HPFL Perforation Through Steel, Cement, and SS**
**Power: 4.4 kW  Beam: CW**

# Large Block Perf Test




Source: SPE 90661

# Large Block Perf Test

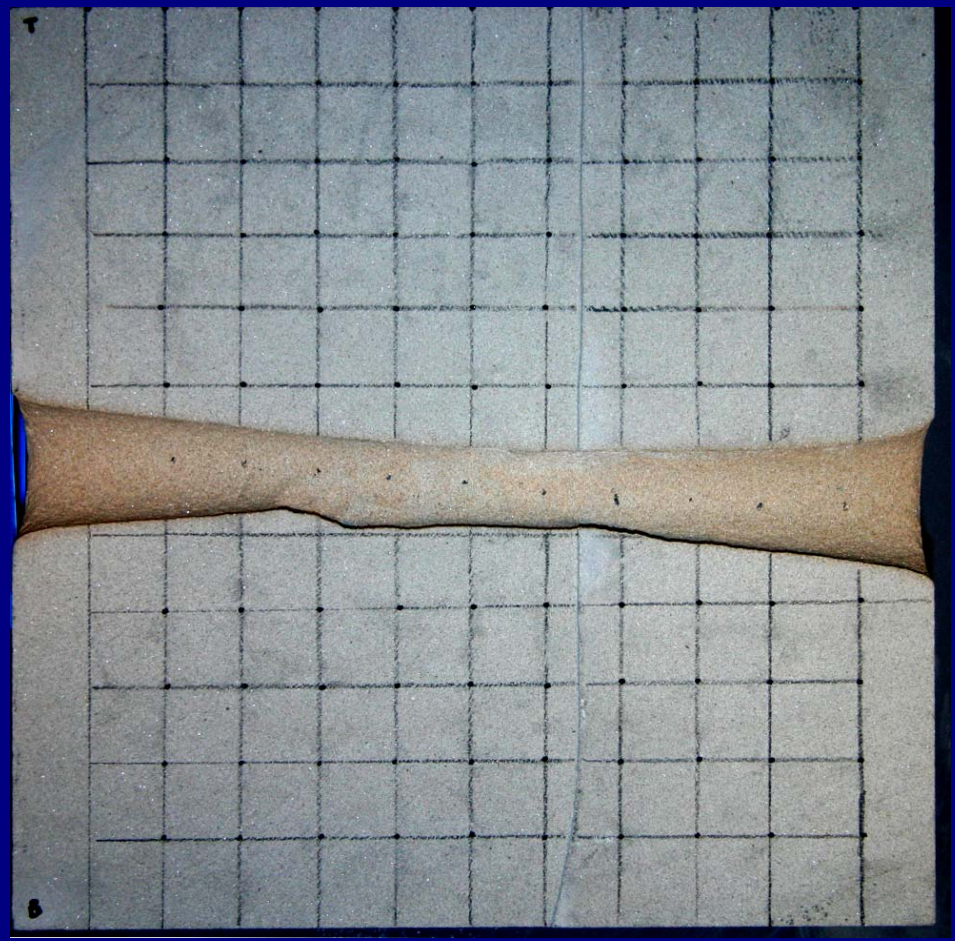



**Temperature Profile During Lasing**

**Source: SPE 90661**

# Large Block Perf Test

## Post-Lase Analysis

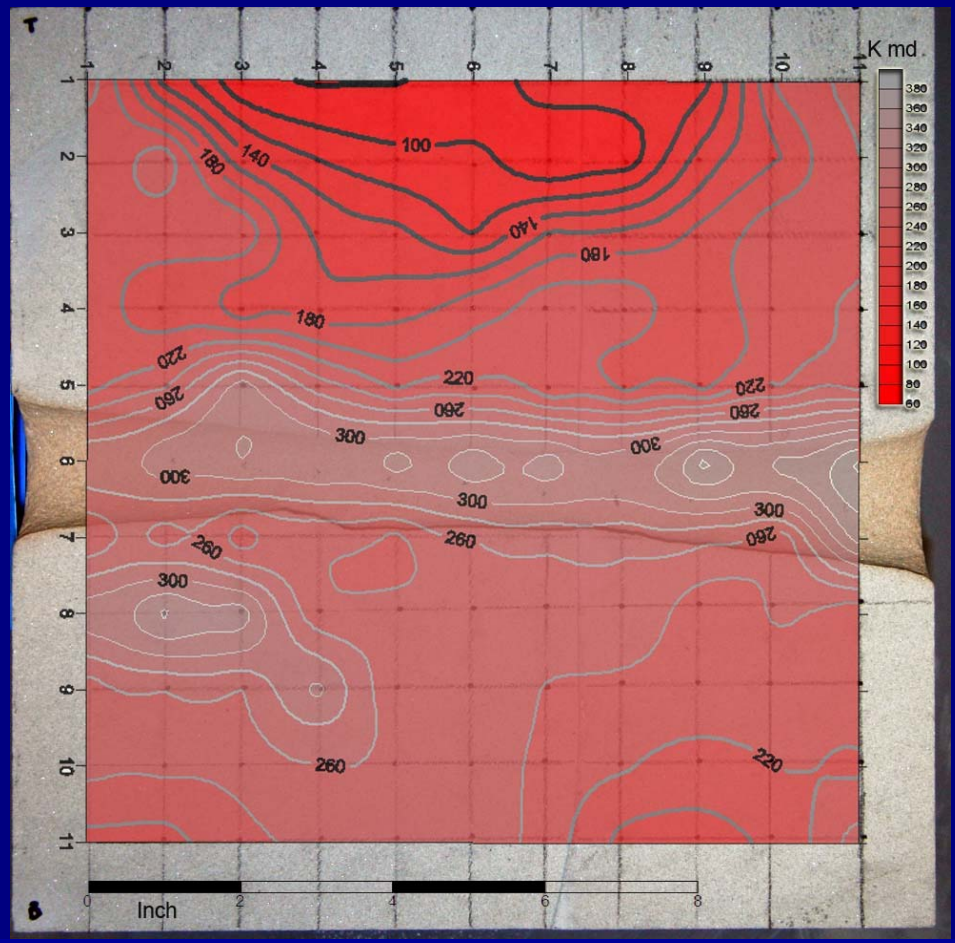


**Tunnel Cutaway**

**Source: ALAC**

# Large Block Perf Test

## Post-Lase Analysis




**Tunnel Cutaway with 2-D Permeability Map**

**Source: ALAC**

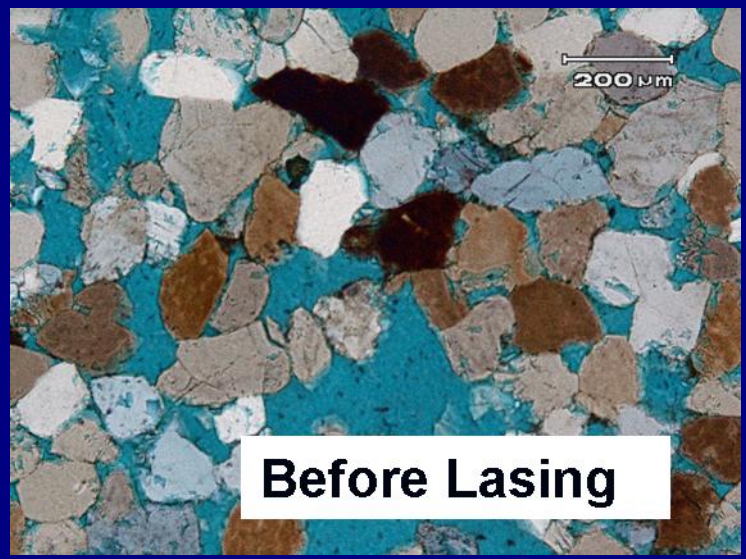
# Large Block Perf Test

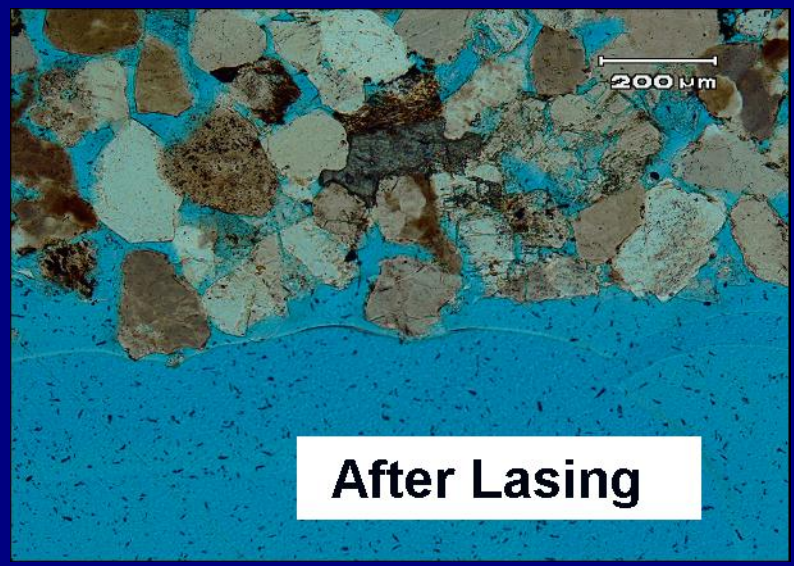
## Post-Lase Analysis


Source: ALAC

# Large Block Perf Test

## Post-Lase Analysis



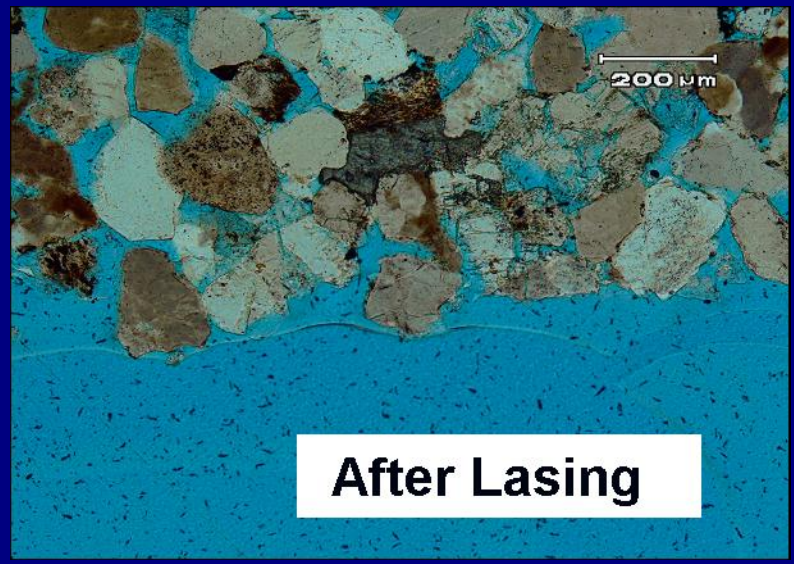

Note: Void Space is Blue

**Source: SPE 90661**

**Thin Section Comparison of Tunnel Surface**

# Large Block Perf Test

## Post-Lase Analysis

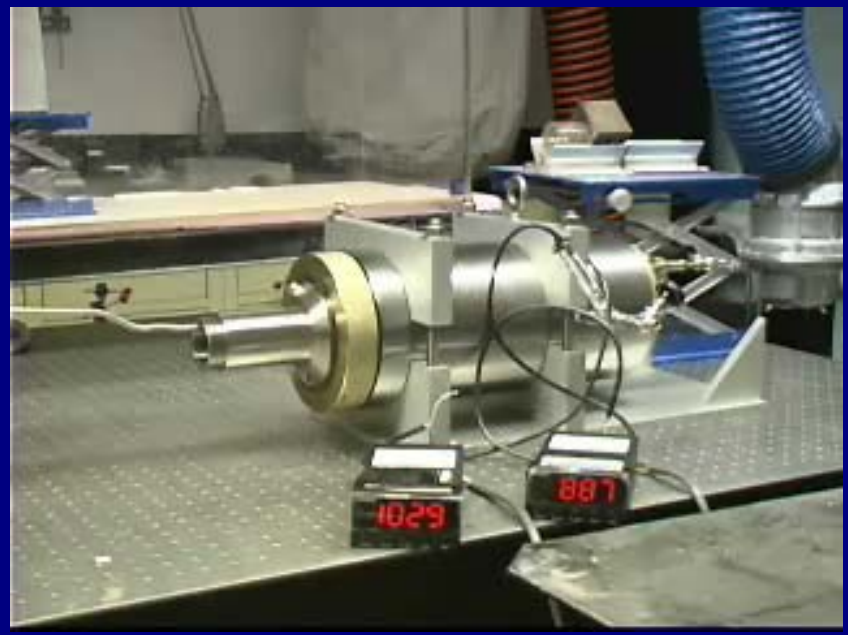

Note: Void Space is Blue

**Source: SPE 90661**

**Thin Section Comparison of Tunnel Surface**

# High Pressure Perf Tests

- High Pressure Cell for Laser Applications
  - Simulates Downhole Pressure Conditions
  - Initial Tests Successful (Triaxial)
  - Testing Under Various Configurations



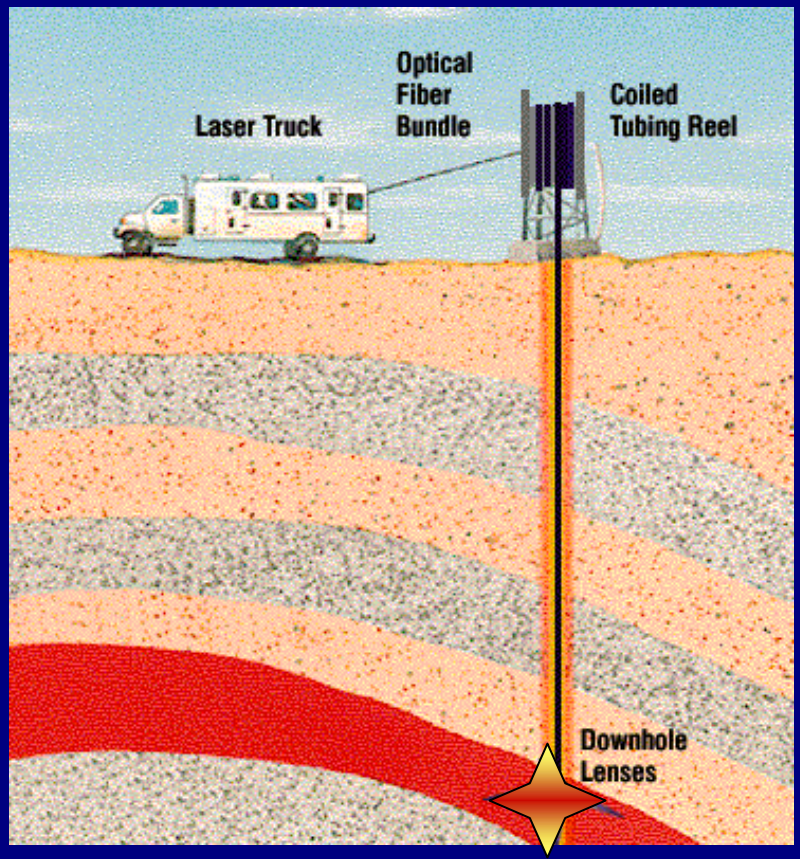

**Source: SPE 97093**

# Presentation Outline

- Laser Applications Background
- Downhole Laser Selection
- Perforation Tests
- HPFL Field Applications Examples
- Summary

# HPFL Field Applications

## Well Completions Concept




Source: ALAC

**Fiber Optics Downhole via CT**

# HPFL Field Application Examples

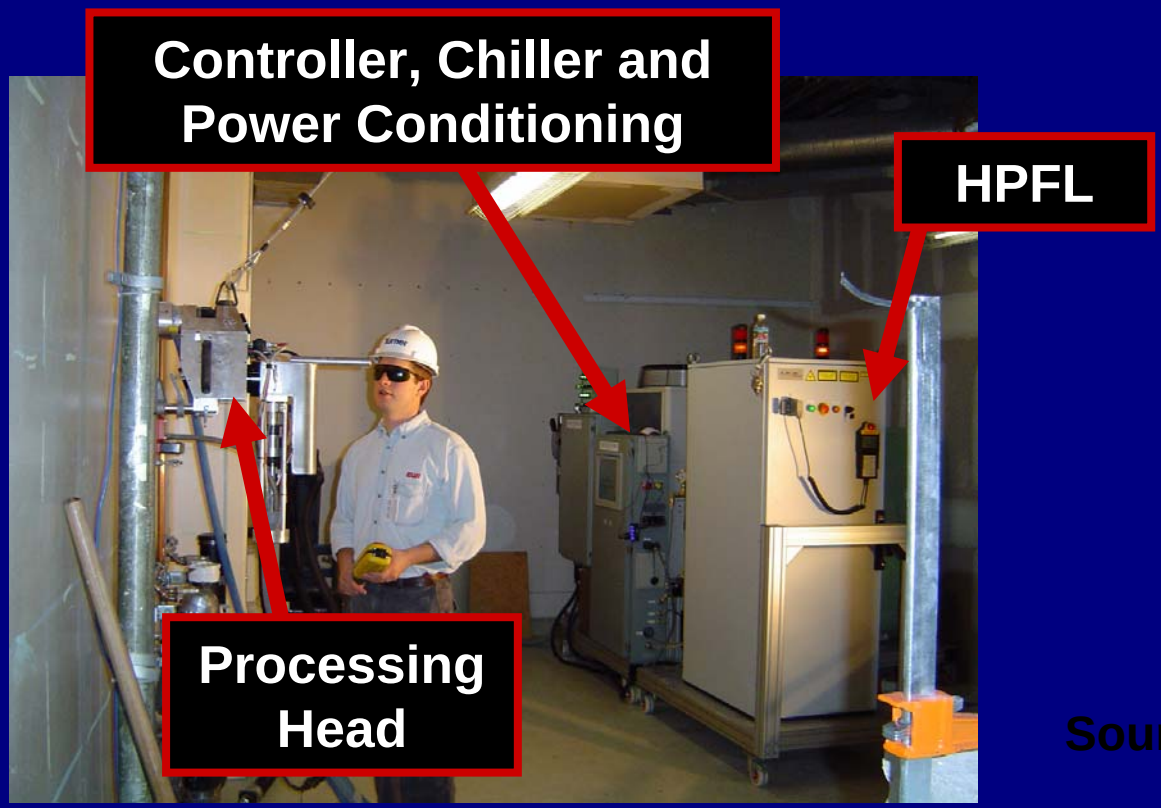
## US Army ZEUS Humvee

# HPFL Field Application Examples

## US Army ZEUS Humvee

# HPFL Field Application Examples

## Earthquake Retrofit of CA Hospital




Source: EWI

**Laser Pilot Bit: 265 mm holes for up to 19.0 mm diameter rebar**

# Presentation Outline

- Laser Applications Background
- Downhole Laser Selection
- Perforation Tests
- HPFL Field Applications Examples
- Summary

# Summary

- Lasers Can Break/Cut All Rock
- Previous Literature Outdated
- Potential Non-Explosive Perf Option
- HPFL: Breakthrough Technology
  - Most Efficient, Reliable Laser Type
  - Meets Field Deployment Needs
  - Commercially Available
  - Over Time: Power ↑, $/kW ↓

# Summary

- Successful Lab Demos
  - Longest Tunnel to Date in SS, LS
  - Minimal Removal Energy Observed
  - Optimal Fluid Flow Conditions Result
  - First In-Situ Laser Perf Study
    - Cuttings Expelled (Underbalanced)
    - Pressure/Stress Improves Cutting Efficiency

# Summary

- Multi-Dimensional Applications
  - Perforation, Slot, Surface Ablation
- Proven Remote Deployment
  - US Army Humvee
  - Construction - CA Hospital
- Multiple Applications in Multiple Industries

# References


- Gahan, B.C. 2006. “High Power Laser Applications for Rock Drilling,” Advanced Laser Applications Conference (ALAC)
- Gahan, B.C., Batarseh, S., Watson, R., Deeg, W. 2005. “Effect of Downhole Pressure Conditions on High-Power Laser Perforation,” SPE 97093
- Batarseh, S., Gahan, B.C., Sharma, B., Gowelly, S. 2004. “Evaluation of High Power Ytterbium Fiber Lasers for Rock Cutting and Removal Applications,” Paper 1402, 23rd ICALEO
- Gahan, B.C., Batarseh, S., Sharma, B., Gowelly, S. 2004. “Analysis of Efficient High-Power Fiber Lasers for Well Perforation,” SPE 90661
- Parker, R.A, et al. 2003. “Laser Drilling: Effects of Beam Application Methods on Improving Rock Removal,” SPE 84353
- Gahan, B.C., Parker, R.A., Batarseh, S., Figueroa, H., Reed, C.B., Xu, Z. 2001. “Laser Drilling: Determination of Energy Required to Remove Rock,” SPE 71466
- O'Brien, D.G., et al. 1999. “StarWars Laser Technology for Gas Drilling and Completions in the 21st Century,” SPE 56625

# Perforating with Lasers: Are You Ready for the Power of Light?

**Brian C. Gahan, PE**
**Laser Rock Technologies LLC**

Society of Petroleum Engineers
Distinguished Lecturer Program
www.spe.org/dl